Detailed Solutions

ESE-2023 Mains Test Series

Civil Engineering Test No : 2

Section A : Highway Engineering + Surveying and Geology

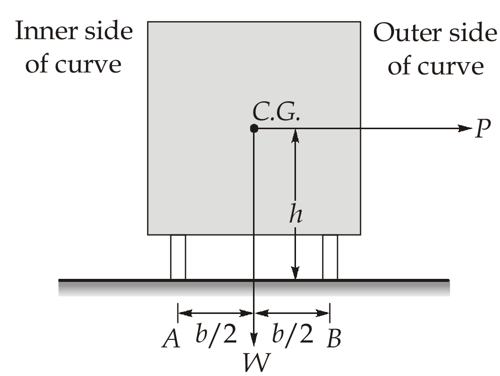
Q.1 (a) Solution:

The centrifugal force acting on a vehicle negotiating a horizontal curve has the following two effects:

1. Tendency to overturn the vehicle about the outer wheels and
2. Tendency to skid the vehicle laterally, outwards.

The analysis of stability of these two conditions against overturning and transverse skidding of the vehicles negotiating horizontal curves without superelevation are as follows:

1. Overturning effect : The centrifugal force tends to overturn the vehicle about the outer-wheel B on the horizontal curve without superelevation.



Let 'h' be the height of the centre of gravity of the vehicle above the road surface and 'b' be the width of the wheel base of the vehicle.

The overturning moment due to centrifugal force = $P \cdot h$

Restoring moment due to weight of the vehicle = $W \cdot \frac{b}{2}$.

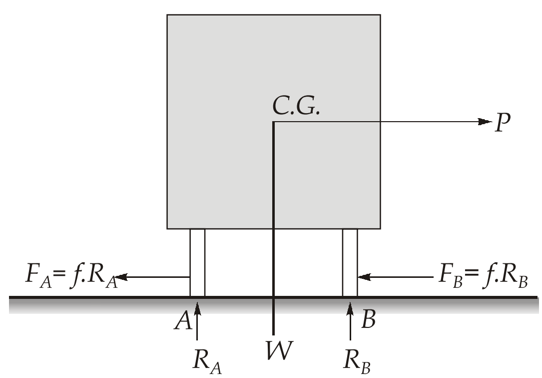
For vehicle to be on the verge of over-turning,

$$P \cdot h = W \cdot \frac{b}{2}$$

$$\Rightarrow \quad \frac{P}{W} = \frac{b}{2h}$$

$\therefore$ If the centrifugal ratio $\frac{P}{W}$ attains a value of $\frac{b}{2h}$, there is danger of overturning.

2. **Transverse skidding effect:** The centrifugal force developed has also the tendency to push the vehicle outwards in the transverse direction.



The equilibrium condition for the transverse skid resistance developed is given by,

$$P = F_A + F_B = f(R_A + R_B) = fW$$

where 'f' is coefficient of friction between the tyre and the pavement surface in the transverse direction, R_A and R_B are normal reaction of the wheels A and B such that $(R_A + R_B)$ is equal to the weight 'W' of the vehicle, as no superelevation has been provided.

$$\therefore \quad \text{Centrifugal ratio, } \frac{P}{W} = f$$

$\therefore$ When centrifugal ratio attains a value equal to coefficient of lateral friction, then there is a danger of lateral skidding.

- Thus to avoid both overturning and lateral skidding on a horizontal curve, the centrifugal ratio should always be less than $\frac{b}{2h}$ and should also be less than transverse friction coefficient, 'f'.

Q.1 (b) Solution:

Mixed traffic flow : Different classes of vehicles such as cars, vans, buses, trucks, auto rickshaws, motor cycles, bicycles, bullock carts etc are found to use the common roadway facilities without segregation on most of the roads in developing countries like India. The flow of traffic with unrestricted mixing of different vehicle classes on the roadways forms the heterogenous traffic flow which is also called as mixed traffic flow.

Concept of PCU value : The PCU may be considered as a measure of the relative space requirement of a vehicle class compared to that of a passenger car under a specified set of roadway, traffic and other conditions.

- If the addition of one vehicle of a particular class in the traffic stream produces the same effect as that due to the addition of one passenger car, then that vehicle class is considered equivalent to the passenger car with a PCU value equal to 1.0.
- The PCU value of a particular vehicle class may be considered as the ratio of the capacity of a roadway when there are passenger cars only to the capacity of the same roadway when there are vehicles of that class only.

Factors affecting PCU value:

- Dimensions of vehicle such as width and length.
- Dynamic characteristics of vehicles such as power, speed, acceleration and braking.
- Transverse and longitudinal gaps or clearances between moving vehicles which depends upon the speed, driver's characteristics and the vehicle classes at the adjoining spaces.
- Traffic stream characteristics such as composition of different vehicle classes, mean speed and speed distribution of the mixed traffic stream and volume to capacity ratio.
- Roadway characteristics such as road geometrics including gradient and curves, access controls, rural or urban road, presence of intersections and the type of intersections.
- Regulation and control of traffic such as speed limit, one way traffic, presence of different control devices etc.
- Environmental and climatic conditions.

Q.1 (c) Solution:

Let x_{A_i} be the individual readings taken by instrument A (for i = 1 to 6) and $\bar{x}_A$ be the mean of the readings taken by A.

No. of observations of A, $n_A = 6$

Similarly, let x_{B_i} be the individual readings taken by instrument B (for i = 1 to 8) and $\bar{x}_B$ be the mean of the readings taken by B.

No. of observations at B, $n_B = 8$

A			B		
x_{A_i} (m)	$\bar{x}_A - x_{A_i}$ (mm)	$(\bar{x}_A - x_{A_i})^2$ (mm^2)	x_{B_i} (m)	$\bar{x}_B - x_{B_i}$ (mm)	$(\bar{x}_B - x_{B_i})^2$ (mm^2)
1002.677	-2	4	1002.678	0	0
1002.671	4	16	1002.682	-4	16
1002.666	9	81	1002.676	2	4
1002.683	-8	64	1002.679	-1	1
1002.673	2	4	1002.676	2	4
1002.680	-5	25	1002.681	-3	9
			1002.678	0	0
			1002.674	4	16
$\bar{x}_A = \frac{\Sigma x_{A_i}}{n_A} = 1002.675\text{m}, \ \Sigma(\bar{x}_A - x_{A_i})^2 = 194$			$\bar{x}_B = \frac{\Sigma x_{B_i}}{n_B} = 1002.678 \text{ m} \ \Sigma(\bar{x}_B - x_{B_i})^2 = 50$		

(i) Standard deviation of measurements done by instrument A,

$$\sigma_A = \pm\sqrt{\frac{\Sigma(\bar{x}_A - x_{A_i})^2}{n_A - 1}} = \pm\sqrt{\frac{194}{5}} = \pm 6.23 \text{ mm}$$

(ii) Standard deviation of measurements done by instrument B,

$$\sigma_B = \pm\sqrt{\frac{\Sigma(\bar{x}_B - x_{B_i})^2}{n_B - 1}} = \pm\sqrt{\frac{50}{7}} = \pm 2.67 \text{ mm}$$

(iii) Relative precision of two instruments

Standard error of the mean for A,

$$\sigma_{mA} = \frac{\sigma_A}{\sqrt{n_A}} = \frac{\pm 6.23}{\sqrt{6}} = +2.54 \text{ mm}$$

Standard error of the mean for B,

$$\sigma_{mB} = \frac{\sigma_B}{\sqrt{n_B}} = \frac{\pm 2.67}{\sqrt{8}} = +0.94 \text{ mm}$$

Let W_{m_A} and W_{m_B} be the weight of the mean readings taken from A and B (1002.675 m and 1002.678 m respectively)

Relative precision of two instruments

$$= \frac{W_{mA}}{W_{mB}} = \frac{\sigma_{mB}^2}{\sigma_{mA}^2} \qquad \left[W \propto \frac{1}{\sigma^2}\right]$$

$$= \frac{0.94^2}{2.54^2} = \frac{1}{7.3}$$

(iv) Most probable length of base line

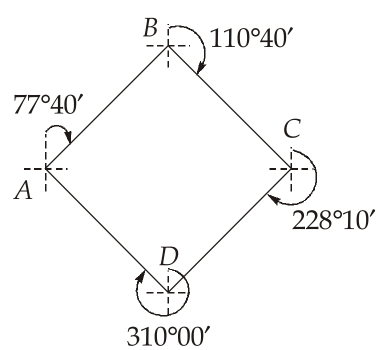
$$\bar{x} = \frac{\bar{x}_A \times W_{m_A} + \bar{x}_B \times W_{m_B}}{W_{m_A} + W_{m_B}} = \frac{\bar{x}_A \times \dfrac{W_{m_A}}{W_{m_B}} + \bar{x}_B}{\dfrac{W_{m_A}}{W_{m_B}} + 1}$$

$$= \frac{1002.675 \times \dfrac{1}{7.3} + 1002.678}{\dfrac{1}{7.3} + 1} \qquad \left[\because \frac{W_{m_A}}{W_{m_B}} = \frac{1}{7.3}\right]$$

$$= 1002.6776 \text{ m}$$

Q.1 (d) Solution:

A rough sketch of the traverse is shown below,



The included angles (interior angles) are calculated as follows:

$$\angle A = \text{Bearing of } AD - \text{brearing of } AB$$
$$= 129°20' - 77°40'$$
$$= 51°40'$$

Similarly,

$$\angle B = 259°20' - 110°40'$$
$$= 148°40'$$
$$\angle C = 289°40' - 228°10'$$
$$= 61°30'$$
$$\angle D = 310°00' - 48°10'$$
$$= 261°50' \text{ (Exterior)}$$
$$= 360° - 261°50' = 98°10' \text{ (Interior)}$$

Sum of angles should be $(2n - 4) \times 90°$

$$= (2(4) - 4) \times 90 = 360°$$

$$\angle A + \angle B + \angle C + \angle D = 51°40' + 148°40' + 61°30' + 98°10' = 360°$$

Thus interior angles are free from any error.

The difference in fore bearing and back bearing of the respective lines is tabulated below,

Line	Difference in Fore Bearing & Back Bearing
AB	259°20′ - 77°40′ = 181°40′
BC	289°40′ - 110°40′ = 179°00′
CD	228°10′ - 48°10′ = 180°00′
DA	310°00′ - 129°20′ = 180°40′

The difference in fore bearing and back bearing of line *CD* is 0. Hence, both the stations *C* and *D* are free from local attraction. This implies that bearings calculated at *C* and *D* are free from any error.

Corrected back bearing of *DA* = Fore bearing of *DA* –180°

= 310°00′ – 180°

= 130°00′

Measured back bearing of *DA* = 129°20′

∴ Correction to be applied in readings from *A*

= 130°00′ – 129°20′ = 40′

∴ Corrected fore bearing of *AB* = 77°40′ + 40′ = 78°20′

Corrected back bearing of *AB* = 78°20′ + 180°00′ = 258°20′

Measured back bearing of *AB* = 259°20′

∴ Correction to be applied in readings from *B*,

= 258°20′ – 259°20′ = –1°00′

∴ Corrected fore bearing of *BC* = 110°40′ – 1°00′ = 109°40′

∴ Corrected back bearing of *BC* = 109°40′ + 180° = 289°40′, which is same as the measured value at station *C* which is free from local attraction as stated earlier.

The final corrected bearings are tabulated below:

Line	Fore Bearing	Back Bearing
AB	78°20′	258°20′
BC	109°40′	289°40′
CD	228°10′	48°10′
DA	310°00′	130°00′

Q.1 (e) Solution:

The principal structural features in rocks includes joints, folds, faults and cleavage. They are described as follows:

- **Joints :** The term joint indicates a crack or a separation in a rock without displacement, or along which no noticeable displacement has taken place. A joint can be open or closed. In general, we have three sets of joints in rocks, one along the bed and the other two at right angles to it. The joints may either be spaced regularly as in columnar basalt or may be irregularly spaced like in rhyolite.

  Joints are important in relation to civil engineering works such as stone quarrying, formation of rock slides, checking availability of ground water etc.

- **Folds:** Folds are defined as undulations or bends that have been developed in rocks due to the stresses caused in the past. They can be alternating ups and downs or crest and trough, the crests are called anticlines and the troughs are called synclines.

  The orientation of the folds is specified by giving its dip and strike. Dip is the inclination of the bed with the horizontal plane in degrees while strike is defined as the direction of a line formed by the intersection of a bedding plane and a horizontal plane. It is basically the direction which the rock layer takes along the horizontal stretch of the country.

  Folding is important in quarrying of sedimentary rocks. They are also important in dam construction as leakage can take place along the folds.

- **Faults:** Fault is commonly defined as a fracture in the rock along which displacement at one side with respect to the other has taken place. A fault is considered 'live' if displacements have occurred along it within 'historic' time otherwise it is considered as 'dead'.

  Identification of fault is very important in civil engineering construction as movement along a fault can considerably affect the structure built on it. Landslides can also take place through the faults as the sides of fault are usually filled with loose materials.

- **Cleavage:** The rock cleavage refers to the property that many rocks possess which is infact splitting along parallel surfaces in certain directions more readily than in others.

  When cleavage develops with folding or faulting, it leads to bed fractures which gives useful data to determination of the nature of folds. It also plays an important role in the determination of shear strength and breakage through layers of rocks used in foundation of dams, spillway, reservoir sites etc.

Q.2 (a) Solution:

(i) Ruling design speed of state highway on rolling terrain as per IRC

$$V = 80 \text{ kmph}$$

$$R_{ruling} = \frac{V^2}{127(e_{max}+f)} = \frac{80^2}{127(0.07+0.15)} = 229.06 \text{ m} \approx 230 \text{ m}$$

(ii) Design of superelevation,

For mixed traffic, $$e = \frac{V^2}{225R} = \frac{80^2}{225 \times 230} = 0.124 > e_{max}$$

$\therefore$ Provide, $e = e_{max} = 0.07$

$$\therefore \quad f = \frac{V^2}{127R} - e = \frac{80^2}{127 \times 230} - 0.07$$

$$= 0.149 < 0.15 \qquad \textbf{(OK)}$$

(iii) Extra widening of pavement

$$W_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}} = \frac{2 \times 6^2}{2 \times 230} + \frac{80}{9.5\sqrt{230}} = 0.71 \text{ m}$$

$\therefore$ Total width of pavement $= 7 + 0.71 = 7.71$ m

(iv) Length of transition curve (L_S)

(*a*) Length of transition curve based on rate of change of centrifugal acceleration,

$$\therefore \quad C = \frac{80}{75+V} = \frac{80}{75+80} = 0.516 \text{ m/sec}^3$$

$$0.5 < C < 0.8 \qquad \textbf{(OK)}$$

$$\therefore \quad L_S = \frac{0.0215V^3}{CR} = \frac{0.0215 \times 80^3}{0.516 \times 230} = 92.75 \text{ m}$$

(*b*) As the terrain is rolling, assume that the pavement is rotated about the centre line of povement at a rate of 1 in 150,

$$L_S = \frac{e(W+W_e)N}{2} = \frac{0.07 \times 7.71 \times 150}{2} = 40.5 \text{ m}$$

(*c*) Minimum value of L_S as per IRC is given by

$$L_S = \frac{2.7V^2}{R} = \frac{2.7 \times 80^2}{230} = 75.13 \text{ m}$$

Adopting the highest of the above three values.

$\therefore$ Design length of transition curve = 92 m

(v) ISD and setback distance

$$\text{ISD} = 2(\text{SSD})$$

$$= 2\left[0.278Vt + \frac{V^2}{254f}\right]$$

$$= 2\left[0.278 \times 80 \times 2.5 + \frac{80^2}{254 \times 0.35}\right] = 255.18 \approx 255 \text{ m}$$

Set back distance (assuming $L_C > S$)

$$S = (R - d)\alpha$$

The distance, d between the centre line of the pavement and the centre line of the inside lane may be taken as one-fourth the width of the pavement at the curve (being a two-lane pavement)

$$= \frac{7.71}{4} = 1.93 \text{ m}$$

$$\therefore \quad \alpha = \left(\frac{S}{R-d}\right) \times \frac{180}{\pi} = \frac{255}{(230 - 1.93)} \times \frac{180}{\pi} = 64°$$

$\therefore$ Set back distance,

$$m = R - (R-d)\cos\frac{\alpha}{2}$$

$$= 230 - (230 - 1.93) \cos 32°$$

$$= 36.6 \text{ m} \approx 37 \text{ m}$$

$\therefore$ The minimum set back distance required to provide a clear vision for the ISD is 37 m.

Q.2 (b) (i) Solution:

Let, l_1, l_2, l_3 and l_4 be the lengths of the respective spans i.e.

$$l_1 = 29.98 \text{ m}, \quad l_2 = 29.89 \text{ m},$$

$$l_3 = 29.84 \text{ m and } \quad l_4 = 29.935 \text{ m}$$

Total length of tape,

$$L = l_1 + l_2 + l_3 + l_4$$

$$= 29.98 + 29.89 + 29.84 + 29.935 = 119.645 \text{ m}$$

Temperature correction:

$$C_t = \alpha(t_m - t_0)l_1 + \alpha(t_m - t_0)l_2 + \alpha(t_m - t_0)l_3 + \alpha(t_m - t_0)l_4$$

$$= \alpha(t_m - t_0)(l_1 + l_2 + l_3 + l_4)$$

$$= \alpha(t_m - t_0)L$$

$$= 0.8 \times 10^{-6} (15 - 20) \times 119.645$$

$$= -0.00048 \text{ m}$$

Pull correction:

$$C_p = \frac{(P-P_0)l_1}{AE} + \frac{(P-P_0)l_2}{AE} + \frac{(P-P_0)l_3}{AE} + \frac{(P-P_0)l_4}{AE}$$

$$= \frac{(P-P_0)}{AE}L$$

$$= \frac{(150-100)\times 119.645}{3.25\times 15\times 10^4 \times \frac{10^6}{10^6}} = 0.01227 \text{ m}$$

Sag correction:

$$C_g = -\frac{w^2 l_1^3}{24P^2} - \frac{w^2 l_2^3}{24P^2} - \frac{w^2 l_3^3}{24P^2} - \frac{w^2 l_4^3}{24P^2}$$

$$= -\frac{w^2}{24P^2}\left(l_1^3 + l_2^3 + l_3^3 + l_4^3\right)$$

$$= \frac{-(0.02\times 9.81)^2}{24(150)^2}(29.98^3 + 29.89^3 + 29.84^3 + 29.935^3)$$

$$= -0.00763 \text{ m}$$

Slope correction:

$$C_s = \frac{-h_1^2}{2l_1} - \frac{h_2^2}{2l_2} - \frac{h_3^2}{2l_3} - \frac{h_4^2}{2l_4}$$

{h_1, h_2, h_3 and h_4 are the elevation differences for span l_1, l_2, l_3 and l_4 respectively}

$$\therefore \quad C_s = \frac{-1}{2}\left[\frac{(0.251)^2}{(29.98)} + \frac{(-0.214)^2}{(29.89)} + \frac{(0.31)^2}{(29.84)} + \frac{(-0.101)^2}{(29.935)}\right]$$

$$= -0.00360 \text{ m}$$

M.S.L. correction:

$$C_{msl} = -\frac{Hl_1}{R} - \frac{Hl_2}{R} - \frac{Hl_3}{R} - \frac{Hl_4}{R} = -\frac{HL}{R} = -\frac{100.4\times 119.645}{6400\times 1000} = -0.00188 \text{ m}$$

$$\therefore \text{ Total correction} = C_t + C_p + C_g + C_s + C_{msl}$$

$$= -0.00048 + 0.01227 - 0.00763 - 0.00360 - 0.00188$$

$$= -0.00132 \text{ m}$$

$$\therefore \text{ Correct length} = 119.645 - 0.00132$$

$$= 119.6437 \text{ m} \approx 119.644 \text{ m}$$

Q.2 (b) (ii) Solution:

Temporary adjustments are the adjustments which are done before making the observation at every setup of the instrument. They consists of setting up the theodolite, levelling it, and focussing the eye piece and objective.

- **Setting up the theodolite:** It consists of centring the theodolite over the station and its approximate levelling by tripod legs. Centring involves setting the theodolite exactly over the station mark by using theodolite while approximate levelling involves levelling the instrument with the legs of the tripod so as to bring the small circular bubble provided on the tribrach in the centre.
- **Levelling:** After setting up the theodolite, levelling is done. It is done to ensure that as the instrument is swung about the vertical axis, the horizontal plate moves in a horizontal plane. It is done with the help of the foot screws.
- **Focussing:** It consists of focussing the eye piece and the objective. The operation of focusing the eye piece is done to make the cross-hairs appear clearly visible while the latter operation is done to bring the image of the object in the plane of the cross-hairs.

Q.2 (c) Solution:

(i) Assumptions:

In order to simplify the analysis, the following assumptions are made:

- When skid marks are present, the skid distances are measured to find the actual braking distances and it is assumed that 100 percent skid has occurred due to braking. When skid marks are not at all visible, it may be assumed as a free collision, without the brakes being applied or due to brake failure.
- When two vehicles of masses m_a and m_b with speeds V_a and V_b collide, if it is assumed that both are perfectly plastic bodies, both would move together with same speed V' after impact; the relationship may be expressed as total momentum before impact is equal to total momentum after impact and may be expressed as:

$$(m_a V_a + m_b V_b) = (m_a + m_b)V'$$

If both the bodies are assumed as perfectly elastic, the coefficient of restitution, e will be unity and the relationship is given by,

$$(V_a - V_b) = (V_b' - V_a')$$

In case the coefficient of restitution, e is less than unity and its value is known, then the relation is :

$$e(V_a - V_b) = (V_b' - V_a')$$

The actual values of the coefficient of restitution should be known, determined experimentally or suitably assumed.

- The impact of the vehicles may be either direct or oblique at a known angle.
- The friction coefficient is assumed to be uniform throughout the skid distance.

(ii) Step-1: Plate load test on subgrade

$$\Delta_1 = 0.5 \text{ cm},$$
$$p = 1.2 \text{ kg/cm}^2,$$
$$a = 15 \text{ cm}$$

Since test is on subgrade, $F_2 = 1$

$$\therefore \quad \Delta_1 = \frac{1.18 \text{ p.a.}}{E_2} \times F_2$$

∴ Modulus of elasticity of subgrade,

$$E_2 = \frac{1.18 \times 1.2 \times 15}{0.5} \times 1 = 42.48 \text{ kg/cm}^2$$

Step-2: Plate load test on base course of thickness 45 cm

$$\Delta_1 = 0.5 \text{ cm},$$
$$p = 7.5 \text{ kg/cm}^2,$$
$$a = 15 \text{ cm},$$
$$h = 45 \text{ cm}$$
$$E_2 = 42.48 \text{ kg/cm}^2$$
$$\Delta_1 = \frac{1.18 \times p_1 a}{E_2} \times F_2$$
$$F_2 = \frac{0.5 \times 42.48}{1.18 \times 7.5 \times 15} = 0.16$$

From Burmister's two-layer deflection factor chart,

For $\frac{h}{a} = 3.0$

and $F_2 = 0.16$

$$\frac{E_1}{E_2} = 20$$

$$\therefore \quad E_1 = 20 \times 42.48 = 849.6 \text{ kg/cm}^2$$

Step-3 : Design wheel load (flexible plate)

$$P = 5000 \text{ kg},$$
$$p = 6 \text{ kg/cm}^2$$

Radius of circular load, $a = \left(\frac{5000}{6 \times \pi}\right)^{1/2} = 16.3 \text{ cm}$

$$E_2 = 42.48 \text{ kg/cm}^2,$$

$$\Delta = 0.5 \text{ cm}$$

$$\Delta = \frac{1.5 \times p \cdot a}{E_2} \times F_2$$

$$F_2 = \frac{0.5 \times 42.48}{1.5 \times 6 \times 16.3} = 0.15$$

From Burmister's two-layer deflection factor chart,

Using curve for $\frac{E_1}{E_2} = 20$, and $F_2 = 0.15$

$$\frac{h}{a} = 4$$

$\Rightarrow$ $h = 4 \times 16.3 = 65.2$ cm

$\therefore$ Design thickness of flexible pavement = 65.2 cm

Q.3 (a) (i) Solution:

Given, Vertical angle, $\theta = 32°18'$

Staff intercept $S' = 1.385 - 0.433 = 0.952$ m

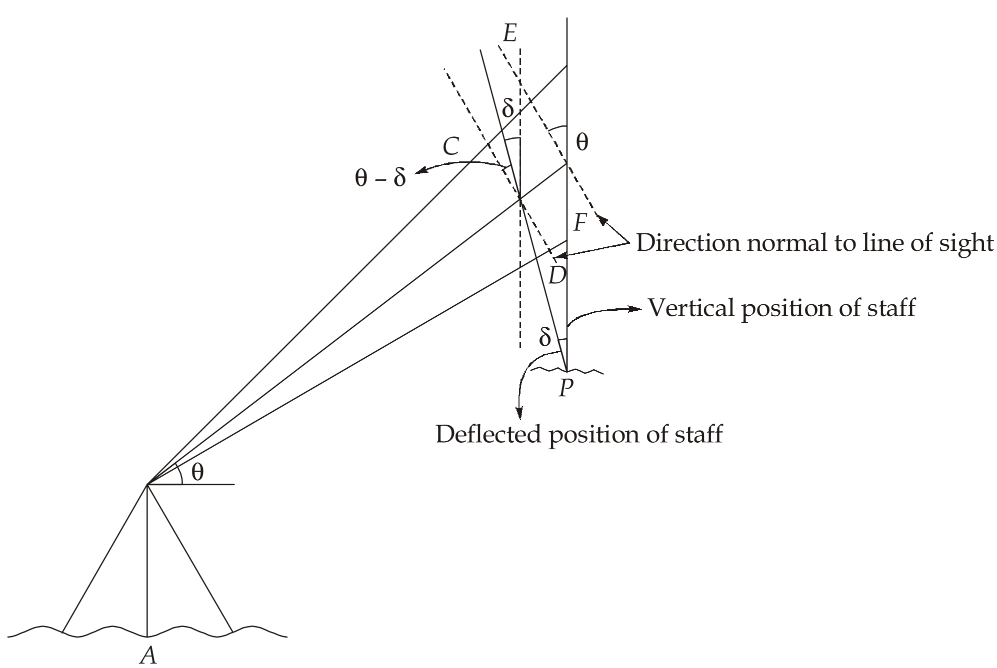
Inclination of staff from vertical, towards the observer $\delta = 1°$

Height of instrument at 'A' = R.L. of Q + Staff reading at Q

= 106.332 + 1.110 = 107.442 m

Let S be the true staff intercept corresponding to the vertical position of staff.

The situation is shown in figure below,



From figure,

$$CD \approx EF$$

$$\Rightarrow \quad S'\cos(\theta - \delta) = S\cos\theta$$

$$\Rightarrow \quad S = \frac{S'\cos(\theta - \delta)}{\cos\theta}$$

Horizontal distance of 'P' from 'A' $= KS\cos^2\theta$

$$= KS'\frac{\cos(\theta - \delta)}{\cos\theta}\cos^2\theta$$

$$= 100 \times 0.952 \times \cos(31°18') \times \cos(32°18')$$

$$= 68.757 \text{ m}$$

$$\text{R.L. of P} = \text{HOI} + KS\cos\theta\sin\theta - S_2$$

$$= \text{HOI} + KS'\cos(\theta - \delta)\sin\theta - S_2$$

$$= 107.442 + 100 \times 0.952 \times \cos(31°18')\sin(32°18') - 0.909$$

$$= 107.442 + 43.467 - 0.909$$

$$= 150.0 \text{ m}$$

Q.3 (a) (ii) Solution:

Remote sensing has applications in a wide spectrum of areas. Some of them are discussed below:

- **Land use and land cover analysis:** One of the prime uses of the satellite remote sensing is in the study of land use and land cover. Land covered with vegetation, building, rocks etc and land use in activities such as agriculture, residences etc can be studied using remote sensing data.
- **Mineral exploration:** Using remote sensing data, valuable ores and minerals, vital to economic development can be discovered. Non-renewable energy resources, such as fossil fuels can also be identified.
- **Environmental studies:** Phenomenon such as global warming and ozone-layer depletion can be continuously monitored using remote sensing data. Similarly, oceanographic studies can also be conducted.
- **Archaeology:** The underlying old settlements can be recognized from remote sensing data and appropriate action can be taken to excavate and study various aspects of old civilizations.
- **Disaster management:** By detecting unusual movements in the earth's crust, earthquake hazards can be predicted. Likewise floods, landslides, forest fires etc can also be detected and appropriate action can be taken.

- **Geomorphology:** Using remote sensing data, geological studies can provide valuable data on faults, tectonic movements, rock-type identification etc.
- **Topography and cartography:** Remote sensing can be used to accurately locate points with reference to ground coordinate systems when ground surveys are difficult or time consuming.
- **Other applications:** Remote sensing data can be used in areas such as defence (studying troop movements), urban planning, traffic studies and so on.

Q.3 (b) Solution:

(i) 1. The parabolic summit curve produces the best riding qualities as it grants uniform rate of change of grade.

The general equation of a parabola with a vertical axis is given by,

$$y = ax^2 + bx + c$$

The slope of this curve at any point is given by

$$\frac{dy}{dx} = 2ax + b$$

The rate of change of slope or rate of change of grade is given by:

$$\frac{d^2y}{dx^2} = 2a = \text{constant}$$

Thus, for a parabola with a vertical axis, the rate of change of grade is uniform and it ensures a comfortable ride.

2. When a fast moving vehicle is travelling along a summit curve, the centrifugal force acts upwards against gravity and hence, a part of the pressure on the tyres and springs of the vehicle is relieved. Hence the problem of causing discomfort to the passengers does not seriously arise on summit curves.

(ii)

$$N_1 = +\frac{1}{50}$$

$$N_2 = -\frac{1}{80}$$

Deviation angle,

$$N = +\frac{1}{50} - \left(-\frac{1}{80}\right) = \frac{13}{400}$$

1. Stopping sight distance :

$$\text{SSD} = 0.278Vt_R + \frac{V^2}{254f}$$

Given, $f = 0.35$

Assume reaction time = 2.5 seconds

$$\text{SSD} = (0.278 \times 100 \times 2.5) + \frac{100^2}{254 \times 0.35} = 181.99 \text{ m} \approx 182 \text{ m}$$

Assume L > SSD :

$$L = \frac{NS^2}{4.4} = \frac{13 \times 182^2}{400 \times 4.4} = 244.67 \text{ m} \approx 245 \text{ m}$$

As this length is greater than SSD, hence assumption is correct

∴ The length of summit curve required is 245 m which is less than prescribed maximum limit of 500 m.

2. **Overtaking sight distance:**

Speed of overtaken vehicle,

$$V_b = (V - 16) \text{ kmph} = (100 - 16) = 84 \text{ kmph}$$

OSD for two lane, two-way highway

$$= d_1 + d_2 + d_3$$

Assume reaction time of driver in case of overtaking = 2 sec

$$d_1 = 0.278 \times 84 \times 2 = 46.704 \text{ m}$$

$$d_2 = 2s + 0.278 \times V_b \times T$$

$$s = 0.2\, V_b + 6 = 0.2 \times 84 + 6 = 22.8 \text{ m}$$

$$T = \sqrt{\frac{4s}{a}} = \sqrt{\frac{4 \times 22.8}{1}} = 9.55 \text{ sec}$$

$$d_2 = (2 \times 22.8) + (0.278 \times 84 \times 9.55) = 268.6116 \text{ m}$$

$$d_3 = 0.278\, VT = 0.278 \times 100 \times 9.55 = 265.49 \text{ m}$$

$$\therefore \quad \text{OSD} = d_1 + d_2 + d_3 = 46.704 + 268.6116 + 265.49$$

$$= 580.8056 \text{ m} \approx 581 \text{ m}$$

As the length, L of the summit curve is to be restricted to 500 m which is less than, the required OSD of 581 m.

Assume L < OSD

$$L = 2s - \frac{9.6}{N} = (2 \times 581) - \frac{9.6 \times 400}{13} = 866.6 \text{ m}$$

As the length of summit curve obtained is higher than the OSD of 581 m and hence the assumption is not correct

Also, it is specified that the length of the summit curve is restricted to a value less than 500 m. Therefore, it is not possible to provide an OSD of 581 m as the length of summit curve is limited to 500 m.

Therefore attempt may be made to design the summit curve, to provide intermediate sight distance (ISD) equal to twice the SSD of 182 × 2 = 364 m

Assume L > ISD :

$$L = \frac{NS^2}{9.6} = \frac{13 \times 364^2}{400 \times 9.6} = 448.55 \text{ m} \simeq 449 \text{ m}$$

As this value is greater than ISD of 364 m, and hence the assumption is correct. As the length of summit curve is 449 m, which is also less than the maximum available length of 500 m, provide a design length of summit curve, L = 449 m which fulfils the requirement of ISD but not OSD.

Q.3 (c) Solution:

Station	B.S. (m)	I.S. (m)	F.S. (m)	Rise (m)	Fall (m)	R.L (m)	Remarks
1	3.25					221.1	
2	1.870		4.05		0.8	220.3	Control Point
3		2.300			0.43	219.87	
4	2.43		1.950	0.35		220.22	Control Point
5		2.540			0.110	220.11	
6	3.10		1.34	1.200		221.31	Control Point
7	1.285		2.110	0.99		222.300	Control Point
8		-2.835		4.12		226.42	Staff held inverted
9	0.72		1.784		4.62	221.80	Control Point
10			1.625		0.905	220.895	
Σ	12.655 m		12.86 m	6.66 m	6.865 m		

- For station - 2,

$$\text{Fall} = 0.8 \text{ m}$$

$$\text{F.S.} = 3.25 + 0.8 = 4.05 \text{ m}$$

- For station - 3,

$$\text{I.S.} = 2.300 \text{ m}$$

$$\text{Fall} = 2.3 - 1.87 = 0.43 \text{ m}$$

- For station - 4,

$$\text{F.S.} = 1.950 \text{ m}$$

$$\text{Rise} = 2.3 - 1.95 = 0.35 \text{ m}$$

Also, station - 5 is at a fall of 0.100 m and so

$$\text{B.S.} = 2.54 - 0.110$$

$$= 2.43 \text{ m}$$

- For station - 6

$$\text{F.S.} = 2.54 - 1.20$$

$$= 1.34 \text{ m}$$

B.S. cannot be computed here as the rise of station - 7 is unknown

- For station - 8

$$\text{Rise} = 2.835 + 1.285 = 4.12 \text{ m}$$

- For station - 9

$$\text{Fall} = 1.785 + 2.835 = 4.62 \text{ m}$$

$$\text{B.S.} = 1.625 - 0.905 = 0.72 \text{ m}$$

Now, $\Sigma B.S = 12.655$ (Given)

So, B.S at station - 6 $= 12.655 - (3.25 + 1.87 + 2.43 + 1.285 + 0.72)$

$= 3.10$ m

Now, for station - 7, $\text{Rise} = 3.10 - 2.110 = 0.99$ m

The summation of B.S., F.S, rise and fall are shown in the table.

Clearly $\Sigma B.S. - \Sigma F.S. = \Sigma \text{ Rise} - \Sigma \text{Fall} = -0.205$ m

Let us calculate the R.Ls of respective stations now.

- For station - 8,

$$\text{R.L.} = 222.3 + 4.12 = 226.42 \text{ m}$$

- For station - 9,

$$\text{R.L.} = 226.42 - 4.62 = 221.8 \text{ m}$$

- For station - 10,

$$\text{R.L.} = 221.8 - 0.905 = 220.895 \text{ m}$$

- For station - 6,

$$\text{R.L.} = 222.3 - 0.99 = 221.31 \text{ m}$$

- For station - 5,

$$\text{R.L.} = 221.31 - 1.20 = 220.11 \text{ m}$$

- For station - 4,

$$\text{R.L.} = 220.11 + 0.110 = 220.22 \text{ m}$$

- For station - 3,

$$\text{R.L.} = 220.22 - 0.35 = 219.87 \text{ m}$$

- For station - 2,

$$\text{R.L.} = 219.87 + 0.43 = 220.3 \text{ m}$$

- For station - 1,

$$\text{R.L.} = 220.3 + 0.8 = 221.1 \text{ m}$$

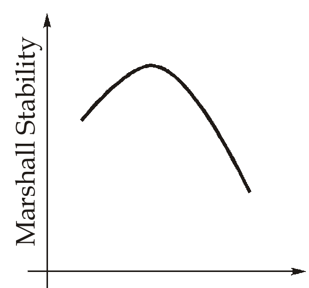
Now, $\text{Last R.L} - \text{First R.L.} = 220.895 - 221.1 = -0.205 \text{ m}$

Thus, $\Sigma\text{B.S} - \Sigma\text{F.S} = \Sigma\text{Fall} = \text{Last R.L.} - \text{First R.L}$

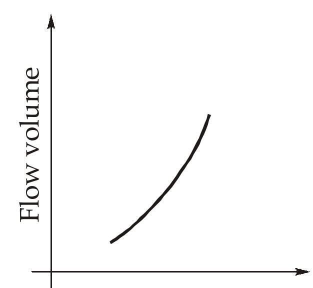
Hence entries filled in the level book are correct.

Q.4 (a) Solution:

(i) 1.



2.



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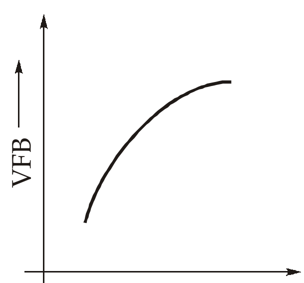

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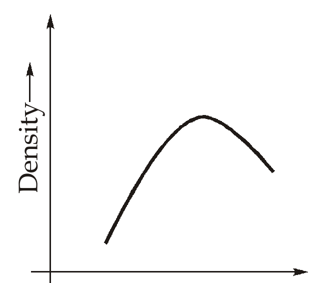
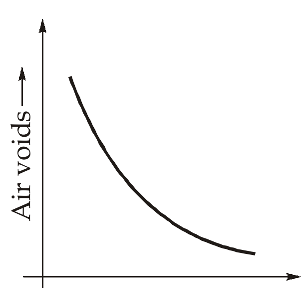


5.



(ii) Radius of relative stiffness, $l = \left[\dfrac{Eh^3}{12k(1-\mu^2)}\right]^{1/4}$

$$\Rightarrow \quad l = \left[\frac{3\times10^5\times18^3}{12\times7(1-0.15^2)}\right]^{1/4} = 67.94 \text{ cm}$$

The equivalent radius of resisting section is computed as below

$$\frac{a}{h} = \frac{15}{18} = 0.833 < 1.74$$

$$b = \sqrt{1.6a^2 + h^2} - 0.675h$$

$$= \sqrt{1.6 \times 15^2 + 18^2} - 0.675 \times 18 = 14 \text{ cm}$$

Stress at the interior,

$$S_i = \frac{0.316P}{h^2}\left[4\log_{10}\left(\frac{l}{b}\right) + 1.069\right]$$

$$= \frac{0.316 \times 4200}{18^2}\left[4 \times \log_{10}\left(\frac{67.94}{14}\right) + 1.069\right]$$

$$= 15.62 \text{ kg/cm}^2$$

Stress at the edge,

$$S_e = \frac{0.572P}{h^2}\left[4\log_{10}\left(\frac{l}{b}\right) + 0.359\right]$$

$$= \frac{0.572 \times 4200}{18^2}\left[4\log_{10}\left(\frac{67.94}{14}\right) + 0.359\right] = 23 \text{ kg/cm}^2$$

Stress at the corner,

$$S_c = \frac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$$

$$= \frac{3 \times 4200}{18^2}\left[1 - \left(\frac{15 \times \sqrt{2}}{67.94}\right)^{0.6}\right] = 19.55 \text{ kg/cm}^2$$

Distance from apex of slab corner to the probable location where the crack is likely to develop due to corner loading,

$$x = 2.58\sqrt{al} = 2.58\sqrt{15 \times 67.94} = 82.36 \text{ cm}$$

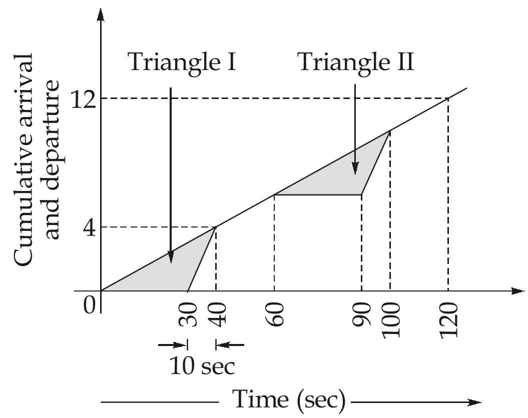
Q.4 (b) Solution:

(i) Between 0 to 120 sec:

Given, q (from 0 -120 sec) = 360 vph

Number of vehicles that arrive in 120 sec

$$= \frac{360}{3600} \times 120 = 12$$



$$\text{Saturation flow rate} = 1440 \text{ vph}$$

$$\therefore \quad 360(t + 30) = 1440 \times t$$

$$\Rightarrow \quad t + 30 = 4t$$

$$\Rightarrow \quad t = 10 \text{ sec}$$

$$\text{Average delay} = \frac{\text{Area of triangle I or II}}{\text{Number of arrivals in a cycle}}$$

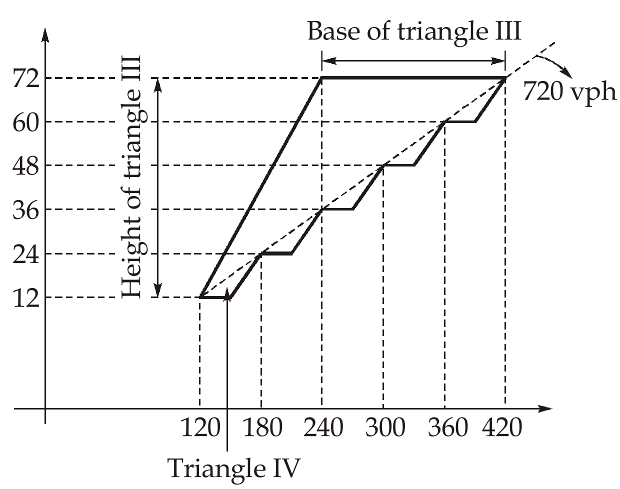
$$\text{Area of triangle I or II} = \frac{1}{2} \times 30 \times 4 = 60$$

Number of arrivals in a cycle

$$= 360 \times \frac{60}{3600} = 6$$

$$\therefore \text{ Average delay between 0 - 120 sec} = \frac{60}{6} = 10 \text{ sec}$$

(ii) Between 120 - 420 sec:



Given, q (from 120 - 240 sec) = 1800 vph

q (from 240 - 420 sec) = 0 vph

The maximum number of vehicles that can cross the intersection from a given approach per unit time

$$= \frac{30}{60} \times 1440 = 720 \text{ vph}$$

Number of vehicles that arrive between 120 - 240 sec

$$= \frac{1800}{3600} \times 120 = 60 \text{ vehicles}$$

Total number of vehicles after 240 sec = 60 + 12 = 72 vehicle

$$\text{Average delay} = \frac{\text{Area of triangle-III} + 5 \times \text{Area of triangle-IV}}{\text{Number of arrivals from 120 - 420 sec}}$$

$$= \frac{\left(\frac{1}{2} \times 180 \times 60\right) + \left(5 \times \frac{1}{2} \times 30 \times 12\right)}{60} = 105 \text{ sec}$$

(iii) Between 0 - 420 sec:

The average delay to all the vehicles between 0 - 420 sec can be obtained by dividing the total delay (faced by all vehicles) by the total number of vehicles.

$$\therefore \text{ Average delay} = \frac{\left(\frac{1}{2} \times 30 \times 4\right) \times 2 + \left(\frac{1}{2} \times 180 \times 60\right) + \left(5 \times \frac{1}{2} \times 30 \times 12\right)}{72} = 89.17 \text{ sec}$$

Q.4 (c) (i) Solution:

1. **Extrusive and intrusive rocks:**
   - **Extrusive rocks:** Extrusive or volcanic, igneous rock is produced when magma exits and cools above the earth's surface. The magma, when it erupts on the surface, cools and solidifies almost instantly leading to the formation of a very fine grained or even a glassy texture. Basalt is an example of extrusive formation.
   - **Intrusive rocks:** Intrusive or plutonic, igneous rock forms when magma is trapped deep inside the earth. The magma remains trapped below, where it cools very slowly over many thousands or million of year until it solidifies. As a result of slow cooling, individual mineral grains have a very long time to grow, so they grow to a relatively large size. They have a coarse grained texture. Granite is an example of intrusive formation.
2. **Acidic and basic rocks:**
   - **Acidic rocks:** These rocks contain dominant quantities of siliceous minerals like quartz and feldspar. They contain more silica (as much as 65%) and are more resistant to chemical weathering. Granite is an example of acidic rock.

- **Basic rocks:** These contain more basic minerals. These contain less silica and larger proportion of calcium, iron, aluminium etc. These basic rocks are more susceptible to chemical attack as compared to acid rocks. Basalt is an example of basic rocks.

Q.4 (c) (ii) Solution:

The weathering of rocks due to the physical and chemical processes that take place in the rocks at or near its surface by the atmospheric agencies, which lead to its disintegration and decomposition, which is called the surface weathering. Another form is the change that takes place deep down the rock, due to the chemical action. Thus, there are two processes that constitute weathering of rocks. They are as follows:

- **Mechanical weathering:**

  In this process, the rock is split into smaller pieces or even soils, but the character of the product of this type of weathering is same as the parent rock. There are two types of mechanical weathering namely **block disintegration** and **granular disintegration**.

  In block disintegration, massive rock is broken into a number of large blocks, while in granular disintegration, loss of cohesion between individual mineral grains takes place.

  The agents of mechanical weathering are:

  (*i*) **Temperature changes**: The alternate cycle of heating and cooling along with the variability in the coefficient of thermal expansion of different minerals result in large strains in the rock and leads to cracking and disintegration.

  (*ii*) **Living things:** Growing of trees in joints of rock can lead to the disintegration of the rock. Similarly, boring by animals also affect the weathering of rocks.

  (*iii*) **Wind and flowing water:** The abrasive effect of wind and flowing water can also lead to the smaller amount of weathering and the effect depends on the intensity of wind and flow of water.

- **Chemical weathering:**

  In the chemical weathering, the product of weathering is different from the parent rock as it undergoes chemical changes. It takes place by the following processes:

  (*i*) **Carbonation**: Carbonation produces a weak acid, called carbonic acid that dissolves rock. It is especially effective at dissolving limestone.

  (*ii*) **Oxidation:** This form of chemical weathering chiefly works on the rocks containing iron. Due to the interaction of oxygen and iron in the presence of water, rust is formed. As rust expands, it weakens the rocks and helps break it apart.

(*iii*) **Hydration:** It is a form of chemical weathering in which the chemical bonds of the mineral are changed as it interacts with water. One instant of hydration occurs when the mineral anhydrate reacts with ground water to transform into gypsum, one of the most common minerals on earth.

(*iv*) **Anhydrite:** In this form of chemical weathering, a new solution is formed as chemicals in rock interact with water. In many rocks, for example, sodium minrals interact with water to form a saltwater solution.

Section B : Strength of Materials -1 + Environmental Engineering -1

Q.5 (a) Solution:

$$\text{Lateral strain} = \frac{\text{Change in lateral dimension}}{\text{Original lateral dimension}}$$

$$= \frac{10 - 9.9975}{10} = 2.5 \times 10^{-4}$$

Now, $$\text{Axial stress } (\sigma) = \frac{P}{A} = \frac{15000}{10 \times 10} = 150 \text{ N/mm}^2$$

$\therefore$ $$\text{Longitudinal strain } (\in) = \frac{\sigma}{E} = \frac{150}{E}$$

But, $$\text{Poisson's ratio } (\mu) = \frac{\text{Lateral strain}}{\text{Longitudinal strain}}$$

$\Rightarrow$ $$\mu = \frac{2.5 \times 10^{-4}}{(150/E)}$$

$\Rightarrow$ $$E = (60 \times 10^4)\,\mu$$

Also, $$\text{Modulus of rigidity } (G) = \frac{E}{2(1+\mu)}$$

$\Rightarrow$ $$8 \times 10^4 = \frac{(60 \times 10^4)\mu}{2(1+\mu)}$$

$\Rightarrow$ $$\text{Poisson's ratio } (\mu) = 0.3636$$

So, $$E = (60 \times 10^4)\,\mu = 60 \times 10^4 \times 0.3636$$
$$= 21.82 \times 10^4 \text{ N/mm}^2$$

Now, $$\text{Bulk modulus } (K) = \frac{E}{3(1-2\mu)} = \frac{21.82 \times 10^4}{3(1 - 2 \times 0.3636)} = 26.66 \times 10^4 \text{ N/mm}^2$$

Also, $$\text{Volume of bar} = 10 \times 10 \times 3000 = 3 \times 10^5 \text{ mm}^3$$

Since, $$K = \frac{p}{\text{Volumetric strain}} = \frac{p}{\left(\frac{dV}{V}\right)}$$

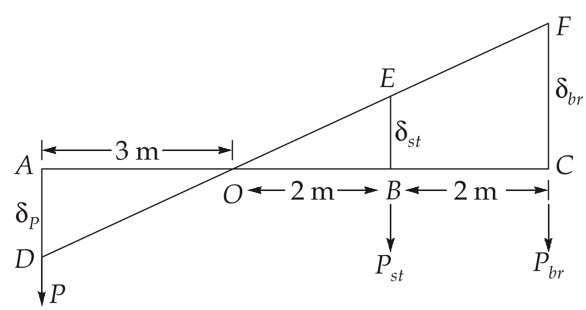
$$\Rightarrow \quad 26.66 \times 10^4 = \frac{150}{\left(\frac{dV}{V}\right)}$$

$$\Rightarrow \quad dV = 3 \times 10^5 \times \frac{150}{26.66 \times 10^4} = 168.79 \text{ mm}^3$$

$\therefore$ Change in volume of bar = 168.79 mm^3

Q.5 (b) Solution:

Free body diagram is shown below,



Taking moments about point O,

$$\Sigma M_O = 0$$

$$\Rightarrow \quad 3 \times P = 2 \times P_{st} + 4 \times P_{br}$$

$$\Rightarrow \quad 3P = 2[\sigma_{st} \times 975] + 4[\sigma_{br} \times 325]$$

$$\Rightarrow \quad 3P = 1950\ \sigma_{st} + 1300\ \sigma_{br}$$

$$\Rightarrow \quad P = 650\ \sigma_{st} + 433.33\ \sigma_{br} \quad \text{...(i)}$$

Now, $$\Delta OBE \sim \Delta OCF$$

$$\Rightarrow \quad \frac{BE}{OB} = \frac{CF}{OC}$$

$$\Rightarrow \quad \frac{\delta_{st}}{2} = \frac{\delta_{br}}{4}$$

$$\Rightarrow \quad \delta_{br} = 2\ \delta_{st}$$

$$\Rightarrow \quad \left(\frac{\sigma L}{E}\right)_{br} = 2\left(\frac{\sigma L}{E}\right)_{st}$$

$$\Rightarrow \quad \frac{\sigma_{br}(2)}{85} = \frac{2 \times \sigma_{st}(1.5)}{210}$$

$$\Rightarrow \qquad \sigma_{br} = 0.6071\ \sigma_{st}$$

When, $(\sigma_{st})_{max} = 160$ MPa

$$\therefore \qquad \sigma_{br} = 0.6071 \times 160$$

$$= 97.136 \text{ MPa} > (\sigma_{br})_{maximum} \qquad \text{(Not OK)}$$

When, $(\sigma_{br})_{max} = 75$ MPa

$$\therefore \qquad \sigma_{st} = \frac{75}{0.6071} = 123.538 \text{ MPa} < (\sigma_{st})_{maximum} \qquad \text{(OK)}$$

So, take $\sigma_{st} = 123.538$ MPa and $\sigma_{br} = 75$ MPa

Using equation (i);

$$P = 650\ \sigma_{st} + 433.33\ \sigma_{br}$$

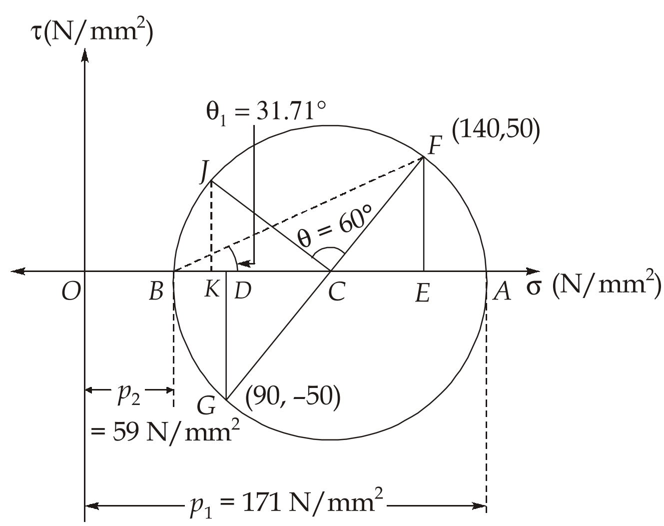
$$\Rightarrow \qquad P = 650(123.538) + 433.33(75)$$

$$\Rightarrow \qquad P = 112799.45 \text{ N} \approx 112.80 \text{ kN}$$

Hence, the required maximum load,

$$P = 112.80 \text{ kN}$$

Q.5 (c) Solution:



Steps: (Assume proper scale for drawing)

1. Mark off $OD = 90$ N/mm^2 and $OE = 140$ N/mm^2.
2. Step off perpendicular offsets $EF = DG = 50$ N/mm^2.
3. With C as the middle point of DE, draw a circle of radius CF or CG and obtain the points A and B.
4. For the plane on which the normal and tangential stresses are required, draw CJ so that angle $JCF = 2 \times 30 = 60°$.

5. Draw JK perpendicular to OC.
6. Principal stresses $p_1 = OA = 171$ N/mm² and $p_2 = OB = 59$ N/mm² by measurement.
7. Position of the principal plane is given by $\theta_1 = \angle FBA = 31°48'$ or 31.71° by measurement.
8. The normal stresses on the plane = OK = 85 N/mm².
9. Tangential stress on the plane = KJ = 47 N/mm².

Q.5 (d) Solution:

Reynold's number, $$\text{Re} = \frac{\phi\rho V d}{\mu} \quad \text{...(i)}$$

where ϕ is shape factor,

V is filtration rate, d is diameter of particle, μ is dynamic viscosity

Putting values in (i), we get

$$\text{Re} = \frac{0.85 \times 1000 \times \left(\frac{5}{3600}\right) \times (0.4 \times 10^{-3})}{1.002 \times 10^{-3}} = 0.47 < 1$$

Now, as per Karman-Cozney equation

$$\frac{h_f}{L} = \frac{f'(1-e)V^2}{e^3 g d} \quad \text{...(ii)}$$

where h_f and L are head loss and depth of bed respectively, e is porosity of bed, d is diameter of particle, f' is friction factor related to coefficient of drag.

Now, for laminar flow, $$f' = \frac{150(1-e)}{\text{Re}} + 1.75 = \frac{150(1-0.4)}{0.47} + 1.75 = 193.24$$

Putting values in (ii), we get

$$\frac{h_f}{L} = \frac{h_f}{1} \frac{193.24 \times (1-0.4) \times \left(\frac{5}{3600}\right)^2}{0.4^3 \times 9.81 \times (0.4 \times 10^{-3})} = 0.89 \text{ m}$$

Q.5 (e) Solution:

Control devices that are used for control of particulate contaminants can be divided into 5 major groups which are as given below:

1. **Gravitational settling chambers:**

   It is a rectangular chamber in which several horizontal trays are fixed. When the polluted gas enters the chambers, its velocity is kept low so that particulate get sufficient time to settle down due to gravity. The high density pollutants settle down at the bottom of chamber which are then removed. Like settling basins in water and wastewater systems, settling chambers provide enlarged areas to minimize horizontal velocities and allow time for vertical velocity to carry the particle to floor of chamber. The largest particle, d_p that can be removed with 100 percent efficiency in a settling chamber can be calculated as $d_p = C\sqrt{\dfrac{18\mu V_h H}{gLP_p}}$

where, V_h = Horizontal velocity of gas, P_p = density of particles, μ = viscosity of air, C = correction factor

Minimum particle size that can be efficiently removed in this type of chamber is greater than 50 μm.

2. **Centrifugal collectors:**

Centrifugal collectors employ a centrifugal force, instead of gravity to separate particle from gas stream. Because centrifugal forces can be generated that are several times greater than gravitational forces, particles can be removed in centrifugal collectors that are much smaller than those can be removed in gravity settling chamber. Two types of centrifugal collectors are generally used i.e. cyclones and dynamic precipitators. In a cyclone precipitator, diameter of particle that is collected with 100 percent efficiency, d_{50} is expressed as,

$$d_{50} = \left(\frac{9\mu b}{2\pi N_e V_i P_p}\right)^{1/2}$$

where, μ = gas viscosity, b = width of cyclone inlet,

N_e = Number of turns within cyclone

V_i = Inlet gas velocity

P_p = Density of particular matter

Minimum size of particles that can be removed from this device is in the range of 5 - 25 μm depending upon the type of device.

3. **Wet collectors:**

Wet collectors remove particulate matter from gas stream by incorporating the particles into liquids droplets directly on contact. Either inertial impringment or interception during gravitational settling may be the contact mechanism. According to the contact-power theory developed for scrubbers, collection efficiency for well-designed wet collectors of all types is a function of energy consumed in air to water contact process. The energy consumed is directly proportional to pressure drop and comparable performance can be expected from all well-designed wet collectors operating at or near the same pressure drop. Minimum particle size that can be removed efficiently in a wet collector is in the range of 0.5 to 10 μm depending upon the type of device.

4. **Fabric filters:**

In this system, particulate laden gas stream passes through a woven or felted fabric that filters out particulate matter and allows the gas to pass through. Small particles are initially retained on fabric by direct interception, inertial impaction, diffusion, electrostatic attraction, and gravitational settling. After a dust mat has formed on the fabric, more efficient collection of submicron particles is achieved by sieving. Minimum size of particle that can be used efficiently in a fabric filter is less than even 1 μm.

5. **Electrostatic precipitator:**

In this system, flue gas is made to pass through highly ionized zone, where the particles get electrically charged and are separated out from gas, with the help of electrostatic forces in powerful electric field. Minimum size of particle that can be removed efficiently in an electrostatic precipitator is greater than 1 μm.

Q.6 (a) Solution:

Alkalinity of water is capacity of water to accept protons. It may be defined as, quantitative capacity of an aqueous medium to react with hydrogen ions to pH 8.3 (phenolphthalein alkalinity) and then to pH 4.5 (methyl orange or total alkalinity). Thus, alkalinity can be defined as ability of water to neutralize acids.

Major sources of alkalinity are:

(*i*) CO_3^{2-} i.e. carbonate alkalinity

(*ii*) HCO_3^- i.e. bicarbonate alkalinity

(*iii*) OH^- i.e. hydroxide or caustic alkalinity

Minor sources of alkalinity are:

$HSiO_3^-$, $H_2BO_3^-$, HPO_4^{2-}, $H_2PO_4^-$ and HS^-.

However, alkalinity due to minor sources are neglected. Alkalinity in water comes due to minerals or due to atmospheric CO_2 mixed in water or due to microbial decomposition of organic matter.

Measurement of alkalinity:

To determine alkalinity of water species, sample of water is titrated with 0.02 N H_2SO_4 by adding a very small phenolphthalein indicator giving the pink color to sample. With addition of acid, pH of sample will start decreasing. At pH of 8.3, pink color of sample will disappear. Till the sample has reached the pH of 8.3, hydrogen ions of acid would have neutralized OH^- ions and CO_3^{2-} ions and the reactions can be expressed as follows:

$$OH^- + H^+ \rightleftharpoons H_2O \quad \text{...(i)}$$

$$CO_3^{2-} + H^+ \rightleftharpoons HCO_3^- \quad \text{...(ii)}$$

However, in (ii) reaction, HCO_3^- still needs H^+ ions to neutralize itself. Hence, it is assumed that till the sample reaches the pH value of 8.3, complete OH^- ions and half of CO_3^{2-} ions i.e. half of carbonate ions would have been neutralized. Let the volume of acid needed till now is '*P*' ml.

Now, after the sample is brought down to pH value of 8.3, titration is again continued and small amount of methyl orange is added. At pH value of 4.5 which is indicated by light pink color, titration is stopped. Let, the volume of acid required in process from starting of titration is '*M*' ml.

Then, total alkalinity of water sample as $CaCO_3$ = Volume of acid added = M mg/l

Given that, Initial pH = 9.5

So, pOH = 14 – 9.5 = 4.5

i.e. $-\log_{10}[OH^-] = 4.5$

$\Rightarrow$ $[OH^-] = 10^{-4.5}$ moles/litre

So, Number of gram equivalents of $[OH^-] = 10^{-4.5} \times 1 = 10^{-4.5}$

So, Caustic alkalinity of water sample = $10^{-4.5} \times 50 \times 1000 = 1.58$ mg/l as $CaCO_3$

Now, acid consumed till 100 ml sample to reach pH of 8.3 = 6.2 ml

So, acid consumed till 1 l sample reaches pH of 8.3 = $\frac{6.2}{100} \times 1000$ = 62 ml

Hence alkalinity of 1 litre sample till pH of 8.3 = 62 mg/l as $CaCO_3$

Therefore, carbonate alkalinity = 2(62 – 1.58) = 120.84 mg/l as $CaCO_3$

Now, total acid used during titration in 100 ml sample = 9.8 + 6.2 = 16 ml

So, Total acid used in 1 litre sample = $\frac{16}{100} \times 1000$ = 160 ml

Therefore, total alkalinity of 1 litre sample = 160 mg/l as $CaCO_3$

Hence, bicarbonate alkalinity = 160 – (120.84 + 1.58)

= 37.58 mg/l as $CaCO_3$

Q.6 (b) (i) Solution:

Strain in fibre at layer *MN*, $\varepsilon_{MN} = \dfrac{0.055}{50} = 1.1 \times 10^{-3}$ (Tensile)

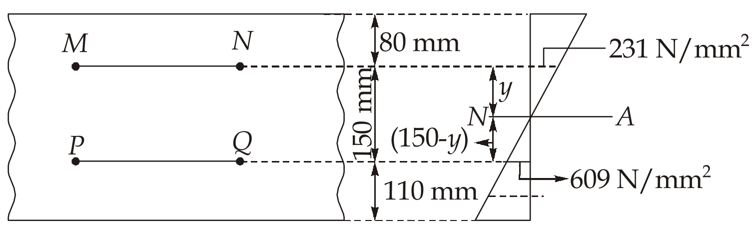
Strain in fibre at layer *PQ*, $\varepsilon_{PQ} = \dfrac{0.145}{50} = 2.9 \times 10^{-3}$ (Compressive)

Hence, stress in fibre layer MN,

$$\sigma_{MN} = \varepsilon_{MN} \cdot E$$
$$= 1.1 \times 10^{-3} \times 2.1 \times 10^{5}$$
$$= 231 \text{ N/mm}^2$$

Similarly, stress in fibre layer *PQ*,

$$\sigma_{PQ} = \varepsilon_{PQ} \cdot E = 2.9 \times 10^{-3} \times 2.1 \times 10^{5}$$
$$= 609 \text{ N/mm}^2$$



Let, the depth of *NA* from *MN* layer be '*y*', hence by geometry of stress distribution diagram,

$$\frac{231}{y} = \frac{609}{(150 - y)}$$

$\Rightarrow$ $y = 41.25$ mm

Hence, depth of N.A. from top fibre = 80 + 41.25 = 121.25 mm

Now, from geometry,

$$\text{Stress at top fibre } (\sigma_t) = \frac{\sigma_t}{121.25} = \frac{231}{41.25}$$

$\Rightarrow$ $\sigma_t = 679 \text{ N/mm}^2$ (Tensile)

Similarly, stress at bottom fibre (σ_b)

$$\frac{\sigma_b}{(340 - 121.25)} = \frac{679}{121.25}$$

$\Rightarrow$ $\sigma_b = 1225 \text{ N/mm}^2$ (Compressive)

Q.6 (b) (ii) Solution:

First bar:

$$\text{Stress, } \sigma = \frac{P}{\frac{\pi}{4}\times(3d)^2} = \frac{4P}{9\pi d^2}$$

$$\text{Strain energy} = \frac{\sigma^2}{2E}\times\text{Volume} = \frac{\left(\frac{4P}{9\pi d^2}\right)^2}{2E}\times\frac{\pi}{4}\times(3d)^2\times L$$

$$= \frac{16P^2}{81\pi^2 d^4\times 2E}\times\frac{\pi}{4}\times 9d^2\times L = \frac{2P^2L}{9E\pi d^2}$$

Second bar:

$$\text{Stress in two end portions} = \frac{P}{\frac{\pi}{4}(3d)^2} = \frac{4P}{9\pi d^2}$$

$$\text{Strain energy in two end portions} = \frac{\sigma^2}{2E}\times\text{Volume}$$

$$= \frac{\left(\frac{4P}{9\pi d^2}\right)^2}{2E}\times\frac{\pi}{4}\times(3d)^2\times\frac{L}{4}\times 2 = \frac{P^2L}{9E\pi d^2}$$

$$\text{Stress in middle half portion} = \frac{P}{\frac{\pi}{4}d^2} = \frac{4P}{\pi d^2}$$

Strain energy in middle half portion

$$= \frac{\left(\frac{4P}{\pi d^2}\right)^2}{2E}\times\frac{\pi}{4}(d)^2\times\frac{L}{2} = \frac{P^2L}{E\pi d^2}$$

$$\text{Total strain energy in second bar} = \frac{P^2L}{9E\pi d^2}+\frac{P^2L}{E\pi d^2} = \frac{10P^2L}{9E\pi d^2}$$

$\therefore$ Ratio of strain energy of two bars

$$= \frac{\left(\frac{2P^2L}{9E\pi d^2}\right)}{\left(\frac{10P^2L}{9E\pi d^2}\right)} = \frac{1}{5}$$

Q.6 (c) (i) Solution:

The destruction of pathogens by chlorination is dependent upon the following factors:

- **Turbidity:** Turbidity in water makes it difficult to obtain free residual chlorine. Also, the penetration of chlorine and therefore the destruction of bacteria in particles of suspended matter of a turbid water may be very uncertain. Due to this reason, application of chlorine is preferred after filtration when water will be free from turbidity.
- **Presence of metallic compounds:** Presence of metallic compounds such as iron and mangnese in water reduces the efficiency of chlorination because they use large amount of chlorine to convert themselves into their higher products of oxidation which are insoluble in water. Hence, it is essential to remove iron and mangnese from water.
- **Ammonia compounds:** The presence of ammonia compounds with or without organic matter may form combined chlorine which is not so effective as compared to free available chlorine.
- **pH of water:** Increasing pH reduces effectiveness of chlorine. Hypochlorous acid, most destructive among other forms of chlorine, is formed in greater quantities at low pH values as is clear from table below:

pH value	Percentage of HOCl in free available chlorine
upto 6.7	90
7	80
8	30
9	5

- **Temperature of water:** Reduction in temperature of water results in substantial decrease in killing power of both free and combined chlorine. In order to have 100% bactericidal activity, requirement of residual chlorine increases with decrease in temperature and increase in pH.
- **Time of contact:** The killing of bacteria depends upon the time of contact between chlorine and microorganisms. The contact time should be decided after taking into account all the factors such as temperature, pH value, type and concentration of microorganisms and form of chlorination.

Q.6 (c) (ii) Solution:

As the water contains $CaCl_2$ and $MgSO_4$, it is evident that sodium alkalinity is not present. Therefore, carbonate hardness of water is equal to alkalinity of water sample and is equal to 250 mg/l as $CaCO_3$. Now,

Lime required

1. Lime required to react with carbonate hardness of 250 mg/l (as $CaCO_3$)

100 mg/l of $CaCO_3$ (alkalinity) requires = 56 mg/l of CaO

So, 250 mg/l of $CaCO_3$ (alkalinity) will require = $\frac{56}{100} \times 250$ = 140 mg/l of CaO

2. Lime required to react with 80 mg/l of $MgSO_4$

120 mg/l of $MgSO_4$ requires = 56 mg/l of CaO

So, 80 mg/l of $MgSO_4$ will require = $\frac{56}{120} \times 80$ = 37.33 mg/l of CaO

So, Total pure lime required = (140 + 37.33)mg/l of CaO

= 177.33 mg/l

85% pure lime required = $\frac{177.33}{0.85}$ = 208.62 mg/l

Lime required for softening of 3 million litres = $208.62 \times 10^{-6} \times 3 \times 10^{6}$ = 625.86 kg

Soda required

Soda is required to react with entire non-carbonate hardness consisting of 80 mg/l of $MgSO_4$ and 60 Mg/l of $CaCl_2$

1. 120 mg/l of $MgSO_4$ requires = 106 mg/l of Na_2CO_3

80 mg/l of $MgSO_4$ will require = $\frac{106}{120} \times 80$ = 70.67 mg/l of Na_2CO_3

2. 110 mg/l of $CaCl_2$ requires = 106 mg/l of Na_2CO_3

60 mg/l of $CaCl_2$ requires = $\frac{106}{110} \times 60$ = 57.82 mg/l of Na_2CO_3

So, total 100% pure soda required = (70.67 + 57.82) = 128.49 mg/l

90% pure soda required = $\frac{128.49}{0.9}$ = 142.77 mg/l

Soda required for softening of 3 million litres = $142.77 \times 3 \times 10^{-6} \times 10^{6}$

= 428.31 kg

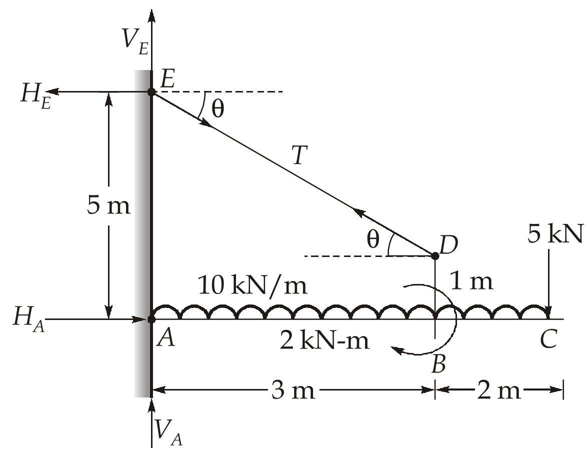
Q.7 (a) Solution:

Let, the horizontal and vertical reaction at E be H_E and V_E and at A be H_A and V_A respectively.

$$\text{Moment about hinge, } E = 0$$

$$\Rightarrow H_A \times 5 - 10 \times 5 \times 2.5 - 2 - 5 \times 5 = 0$$

$$\Rightarrow \quad H_A = 30.4 \text{ kN } (\rightarrow)$$



Resolving the forces on structure horizontally

$$H_E = 30.4 \text{ kN } (\leftarrow)$$

Let, the tension in tie DE be T

Hence at point E, resolving the forces

$$T \sin\theta = V_E$$

$$T \cos\theta = H_E$$

$$\tan\theta = \frac{V_E}{H_E}$$

From geometry, $\qquad \tan\theta = \dfrac{4}{3}$

$$\therefore \quad V_E = \frac{4}{3} \times H_E = \frac{4}{3} \times 30.4 = 40.53 \text{ kN}$$

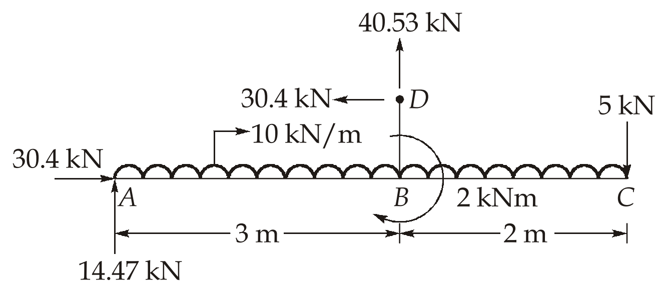
Resolving forces on structure vertically

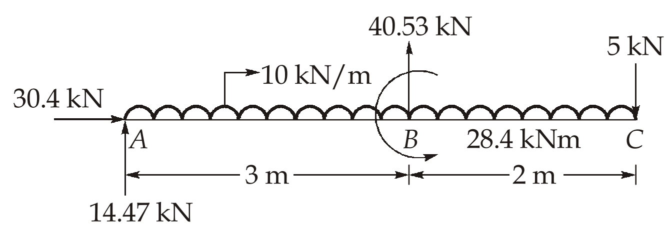
$$V_E + V_A = 10 \times 5 + 5$$

$$\Rightarrow \quad V_A = 55 - 40.53$$

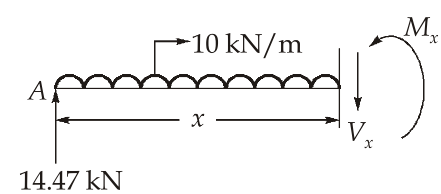
$$= 14.47 \text{ kN}$$

Now, forces acting on the beam ABC are as shown below,





Section AB ($0 \le x \le 3$ m)



$$V_x = 14.47 - 10x$$

$$M_x = 14.47x - \frac{10x^2}{2}$$

$\Rightarrow$ $$M_x = 14.47x - 5x^2$$

At point A ; $x = 0$

$\therefore$ $$S.F = 14.47 \text{ kN}$$

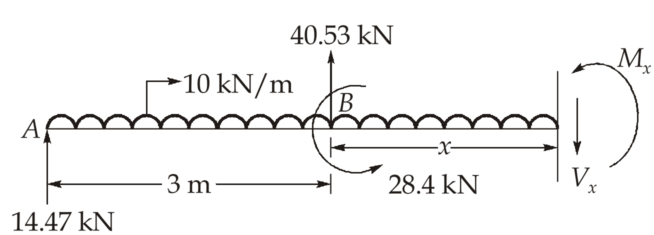
and $$B.M. = 0 \text{ kNm}$$

At point B ; (just left of B) ($x = 3$ m)

$$S.F = 14.47 - 10 \times 3 = -15.53 \text{ kN}$$

and $$B.M. = 14.47 \times 3 - 5 \times 3^2 = -1.59 \text{ kNm}$$

Section BC ($0 \le x \le 2$ m)



$$V_x = 14.47 - 10 \times 3 + 40.53 - 10x$$

$\Rightarrow$ $$V_x = 25 - 10x$$

$$M_x = 14.47(3 + x) + 40.53(x) - \frac{10(3 + x)^2}{2} - 28.4$$

$\Rightarrow$ $M_x = 14.47(3 + x) + 40.53(x) - 5(3 + x)^2 - 28.4$

At point B (just right of B) at $x = 0$ m;

$$SF = 25 \text{ kN}$$

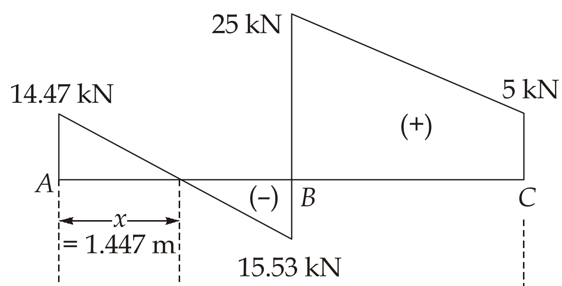
$$BM = 14.47 \times 3 - 5 \times 9 - 28.4 = -29.99 \text{ kNm} \approx -30 \text{ kNm}$$

At point C (just left of C) at $x = 2$ m;

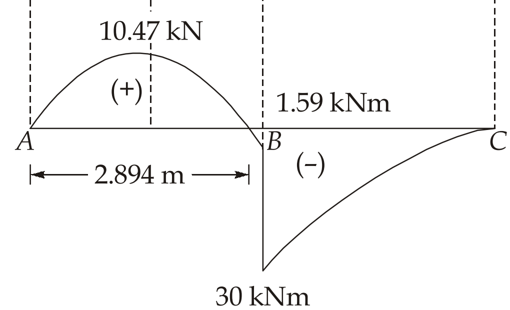
$$SF = 25 - 10 \times 2 = 5 \text{ kN}$$

$$BM = 14.47 \times 5 + 40.53 \times 2 - 5(5)^2 - 28.4 = 0.01 \text{ kNm}$$

SFD and BMD:



Shear force diagram



Bending moment diagram

To find the point of location of zero $S.F.$,

From SF diagram; $\dfrac{14.47}{x} = \dfrac{15.53}{(3 - x)}$

$\Rightarrow$ $x = 1.447$ m (from A)

Bending moment at $x = 1.447$ m

$$BM_{x = 1.447 \text{ m}} = 14.47 \times 1.447 - 5 \times 1.447^2$$

$$= 10.47 \text{ kNm}$$

Maximum bending moment $= -30$ kNm

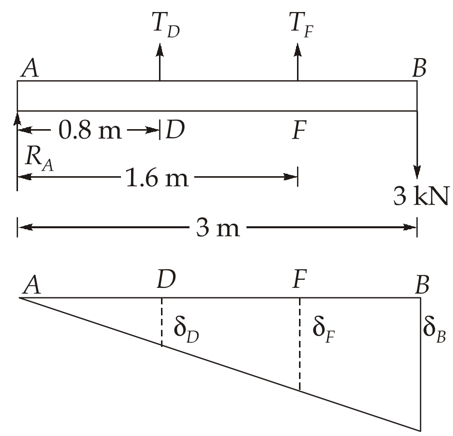
Location of point of contraflexure:

$$M_x = 0 = 14.47x - 5x^2$$

$$\Rightarrow \quad x = \frac{14.47}{5} = 2.894 \text{ m (from } A)$$

Q.7 (b) Solution:

(i) Free body diagram and displacement diagram as shown below,



Taking moments at A:

$$\Sigma M_A = 0$$

$$\Rightarrow \quad T_D \times 0.8 + T_F \times 1.6 = 3 \times 3$$

$$\Rightarrow \quad 0.8T_D + 1.6T_F = 9 \quad \text{...(i)}$$

Now, from displacement diagram:

$$\frac{\delta_D}{0.8} = \frac{\delta_F}{1.6}$$

$$\Rightarrow \quad \delta_F = 2\delta_D \quad \text{...(ii)}$$

Force-displacement relations,

$$\delta_D = \frac{T_D \cdot L_{CD}}{E \cdot A_{CD}} \text{ and } \delta_F = \frac{T_F \cdot L_{EF}}{E \cdot A_{EF}} \quad \text{...(iii)}$$

From equation (ii) and (iii),

$$\Rightarrow \quad \frac{T_F \cdot L_{EF}}{E \cdot A_{EF}} = 2 \times \frac{T_D \cdot L_{CD}}{E \cdot A_{CD}}$$

$$\Rightarrow \quad \frac{T_F \times 2}{\frac{\pi}{4}(0.003)^2} = \frac{2 \times T_D \times 5}{\frac{\pi}{4} \times (0.012)^2}$$

$$\Rightarrow \quad T_F = 0.3125T_D \quad \text{...(iv)}$$

Substituting (iv) in equation (i),

$$0.8T_D + 1.6(0.3125T_D) = 9$$

$$\Rightarrow \quad T_D = 6.923 \text{ kN}$$

and $\quad T_F = 0.3125 \times 6.923 = 2.163 \text{ kN}$

Hence, stress in wire, $CD = \dfrac{T_D}{\frac{\pi}{4}\times(0.012)^2} = \dfrac{6.923}{\frac{\pi}{4}\times(0.012)^2}$

$$= 61212.76 \text{ kN/m}^2 = 61.21 \text{ MPa}$$

Stress in wire, $EF = \dfrac{T_F}{\frac{\pi}{4}\times(0.003)^2} = \dfrac{2.163}{\frac{\pi}{4}\times(0.003)^2}$

$$= 306001.90 \text{ kN/m}^2 = 306.00 \text{ MPa}$$

(ii) Downward displacement at end B,

$$\frac{\delta_F}{1.6} = \frac{\delta_B}{3}$$

$$\Rightarrow \quad \delta_B = \frac{3}{1.6}\times\left(\frac{T_F}{A_{EF}}\right)\frac{L_{EF}}{E}$$

$$\Rightarrow \quad \delta_B = \frac{3}{1.6}\times\frac{306\times2000}{2.1\times10^5}$$

$$\Rightarrow \quad \delta_B = 5.464 \text{ mm}$$

Q.7 (c) (i) Solution:

- **Lapse rate:** In the troposphere, temperature of ambient (surrounding) air normally decreases with an increase in height. This rate of (decrease in) temperature with increase in height is called lapse rate.
- **Environmental lapse rate:** Lapse rate differ from place to place and from time to time even at the same place. The prevailing lapse rate at a particular time and place can be determined by sending up a ballon equipped with thermometer and with a self recording mechanism. This is known as 'Environmental lapse rate (ELR)' or ambient lapse rate.
- **Adiabatic lapse rate:** Under the prevailing environmental conditions, when a parcel of air, which is hotter and lighter than surrounding air is released, then naturally it tends to rise up, until it reaches to a level, at which its own temperature and density becomes equal to that of air surrounding it, at that height. Hence when a pocket of

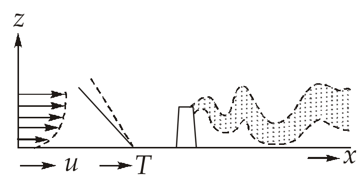
artificially heated air is emitted into environment, it rises up, expands, becomes lighter and gets cooled. The rate at which the temperature decreases, as this parcels gain height may be different from ELR. This internal decrease of temperature with height, which occurs in rising parcel of air mass can be calculated by assuming process to be adiabatic. Using the law of conservation of energy and gas laws, this rate of decrease of temperature with height can be calculated and is known as 'adiabatic lapse rate'.

Q.7 (c) (ii) Solution:

Dispersion is the process of spreading out pollution emission over a large area and thus reducing their concentration i.e. it is a process of dilution. Wind speed and environmental lapse rates directly influence the dispersion pattern. **Seven classifications of plume behavior** which may occur under some commonly encountered metrological conditions are discussed below:

(i) Looping Plume:

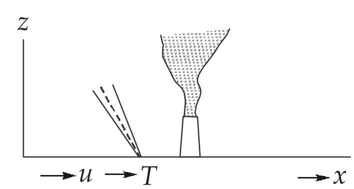
Under super-adiabatic condition, both upward and downward movement of the plume is possible. Large eddies of a strong wind cause a looping pattern. Although the large eddies tend to disperse pollutants over a wide region, high ground level concentrations may occur close to the stack.



Looping plume

(ii) Neutral Plume:

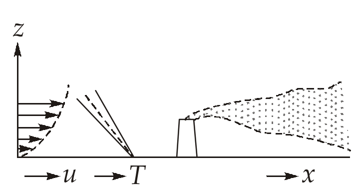
Neutral plume is the upward vertical rise of the plume from the stack, which occurs when the environmental lapse rate is equal to or very near to the adiabatic lapse rate. The upward lifting of the plume will continue till it reaches in air of density similar to that of the plume itself.



Neutral plume

(iii) Coning Plume:

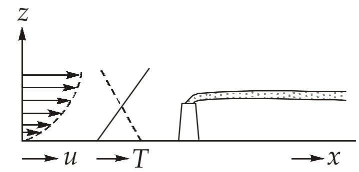
A coning plume occurs under essential neutral stability when environmental lapse rate is equal to adiabatic lapse rate and moderate to strong winds occur. The plume enlarges in the shape of a cone. A major part of pollution may be carried fairly far downwind before reaching ground.



Coning plume

(iv) Fanning Plume:

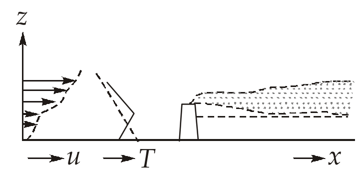
A fanning plume occurs in the presence of a negative lapse rate when vertical dispersion is restricted. The pollutants disperse at the stack height, horizontally in the form of a fanning plume.



Fanning plume

(v) Lofting Plume:

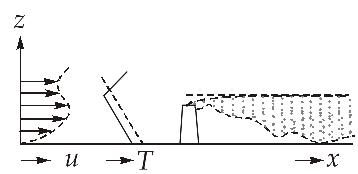
When the stack is sufficiently high and the emission is above an inversion layer then mixing in the upward direction is uninhibited, but downward motion is restricted. Such lofting plumes do not result in any significant concentration at ground level. However, the pollutants are carried hundreds of kilometers from the source.



Lofting plume

(vi) Fumigating Plume:

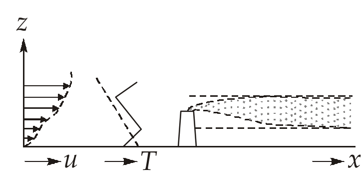
When the emission from the stack is under an inversion layer, the movement of the pollutants in the upward direction is restricted. The pollutants move downwards. The resultant fumigation can lead to a high ground level concentration downwind of the stack.



Fumigating plume

(vii) Trapping Plume:

When inversion layers exist above the emission source, as well as below the source, then naturally, the emitted plume will neither go up, nor will it go down, and would remain confined between the two inversions. Such a plume is called a trapping plume, and is considered bad condition for dispersion, as the dispersion cannot go above a certain height.



Trapping plume

Q.8 (a) (i) Solution:

Year	Population (in thousand)	Increase in Population in each decade (in thousand)	%age increase in population i.e. growth rate (r)
1981	104		
1991	126	22	21.15%
2001	161	35	27.78%
2011	219	58	36.02%

Now, geometric mean of growth rate (r)

$$= \sqrt[3]{21.15 \times 27.78 \times 36.02} = 27.66\% \text{ per decade}$$

Now,
$$P_x = P_0\left(1+\frac{r}{100}\right)^n$$

$$P_0 = 219000$$

$$r = 27.66\% \text{ per decade}$$

$$n = 1$$

Putting values, we get

$$P_{2021} = 219000\left(1+\frac{27.66}{100}\right) = 279575.4 = 279576 \text{ (say)}$$

Q.8 (a) (ii) Solution:

The annual average demand for water (i.e. per capita demand) considerably varies for different towns and cities. This figure generally ranges between 100 to 360 litres/capita/day for Indian conditions. The variations in total water consumption of different cities or towns depend upon various factors, which must be thoroughly studied and analyzed before fixing the per capita demand for design purpose. These factors are discussed below:

- **Size of the City:** The total water demand depends on size of population and for the design of water supply scheme for a given population size, the following guidelines may be adopted:

Variation in Per Capita Demand (q) with population in India		
S. No.	**Population**	**Per Capita Demand in Liters/day/Person**
1.	Less than 20000	110
2.	20000 - 50000	110 - 150
3.	50000 - 2 Lakhs	150 - 240
4.	2 Lakhs - 5 Lakhs	240 - 275
5.	5 Lakhs - 10 Lakhs	275 - 335
6.	Over 10 Lakhs	335 - 360

- **Climatic Conditions:** In hot and dry places, the consumption of water is generally more, because more of bathing, cleaning, air-coolers, air-conditioning etc. are involved.

Similarly, in extremely cold countries, more water may be consumed, because the people may keep their taps open to avoid freezing of pipes and there may be more leakage from pipe joints since metals contract with cold.

- **Types of Gentry and Habits of People:** Rich and upper class communities generally consume more water due to their affluent living standards.
- **Industrial and Commercial Activities:** The presence of industrial and commercial activities at a particular place increase the water consumption by a large amount.
- **Quality of Water Suppy:** If the quality and taste of the supplied water is good, then it will be consumed more, because in that case, people will not use other sources such as private wells, hand pumps, etc. Similarly, certain industries which require standard quality waters, will not develop their own supplies and will use public supplies, provided the supplied water is upto their required standards.
- **Pressure in the Distribution Systems:** If the pressure in the distribution pipes is high and sufficient to make the water reach at 3rd or even 4th storey, water consumption shall be definitely more.

  This water consumption increases because of two reasons:

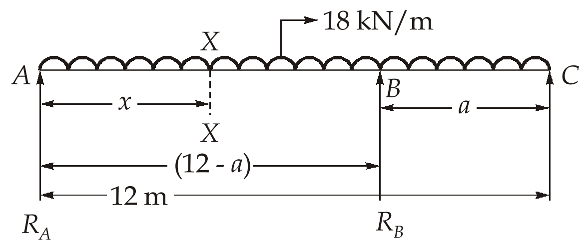
  (*i*) People living in upper storeys will use water freely as compared to the case when water is available scarcely to them.

  (*ii*) The losses and waste due to leakage are considerably increased if their pressure is high.

- **Development of Sewerage Facilities:** The water consumption is more, if the city is provided with a 'flush system' and it is less if the old 'conservation system' of latrines is adopted.
- **System of Supply:** Water may be supplied either continuously for 24 hours of the day, or may be supplied only for peak period during morning and evening. The second system, i.e. intermittent supplies, may lead to some saving in water consumption due to losses occurring for lesser time and a more vigilant use of water by the consumers.
- **Cost of Water:** If the water rates are high, lesser quantity may be consumed by the people. This may not lead to large savings as the affluent and rich people are little affected by such policies.
- **Policy of Metering and Method of Charging:** When the supplies are metered, people use only that much of water as much is required by them. Although metered supplies are preferred because of lesser wastage, they generally lead to lesser water consumption by poor and low income group, leading to unhygienic conditions.

Q.8 (b) Solution:

(i) Let us assume that the second support be at B, located at 'a' meters from C



Taking moments about end A,

$$\Rightarrow \quad R_B(12 - a) - 18 \times 12 \times 6 = 0$$

$$\Rightarrow \quad R_B = \frac{1296}{(12-a)} \quad ...(i)$$

Hence, $$R_A = 18 \times 12 - \frac{1296}{(12-a)}$$

$$\Rightarrow \quad R_A = \frac{1296 - 216a}{(12-a)} \quad ...(ii)$$

Bending moment at support B,

$$M_B = -18 \times a \times \frac{a}{2} = -9a^2 \quad ...(iii)$$

Maximum positive bending moment occurs at section X-X between supports A and B.

Suppose, this section is at distance x from support A.

For maximum BM at section X-X

$$(\text{SF})_{XX} = 0$$

$$\Rightarrow \quad R_A - 18 \times x = 0$$

$$\Rightarrow \quad \frac{1296 - 216a}{(12-a)} - 18x = 0$$

$$\Rightarrow \quad x = \frac{1296 - 216a}{18(12-a)} \quad ...(iv)$$

Hence, maximum positive bending moment at section X-X is,

$$M_{XX} = R_A \cdot x - 18 \times \frac{x^2}{2}$$

$$= \frac{(1296-216a)}{(12-a)} \times \frac{(1296-216a)}{18(12-a)} - 9\left(\frac{1296-216a}{18(12-a)}\right)^2$$

$$= \left[\frac{(1296-216a)}{(12-a)}\right]^2 \left[\frac{1}{18} - \frac{9}{18^2}\right]$$

$$M_{XX} = \frac{1}{36}\left[\frac{1296-216a}{12-a}\right]^2 \quad \text{...(v)}$$

For the condition that maximum bending moment will be as small as possible, the maximum sagging and hogging moment over the support should be numerically equal.

Equating equation (iii) and (v),

$$\Rightarrow \quad \frac{1}{36}\left[\frac{1296-216a}{12-a}\right]^2 = 9a^2$$

$$\Rightarrow \quad \left[\frac{1296-216a}{12-a}\right]^2 = 9 \times 36a^2$$

$$\Rightarrow \quad \frac{1296-216a}{12-a} = 18a$$

and $$\frac{1296-216a}{12-a} = -18a$$

$\Rightarrow \quad 1296 - 216a = 216a - 18a^2$

and $\quad 1296 - 216a = -216a + 18a^2$

$\Rightarrow \quad 18a^2 - 432a + 1296 = 0$

and $\quad 18a^2 = 1296$

On solving, we get

$\Rightarrow \quad a = 3.5147$ and 20.485

Hence, $\quad a = 3.5147 \approx 3.515$ m

(as a can not be greater than 12 and adopting a lower value of 'a' so that bending moment is smaller)

Position of second support should be at 3.515 m from right end.

Now,

Maximum bending moment $= 9a^2 = 9(3.515)^2 = 111.197$ kNm

(ii)

$$W = mg = 40 \text{ kg} \times 9.81 \text{ m/s}^2 = 392.4 \text{ N}$$

$$A = 50 \text{ mm}^2$$

$$E = 130 \text{ GPa} = 130 \times 10^3 \text{ MPa}$$

$$h = 1.2 \text{ m}$$

$$\sigma_{allowable} = \sigma_{max} = 700 \text{ MPa}$$

$$\text{Static stress } (\sigma_{st}) = \frac{W}{A} = \frac{392.4}{50} = 7.848 \text{ MPa}$$

We know,

$$\sigma_{max} = \sigma_{st}\left[1 + \sqrt{1 + \frac{2h}{\delta_{st}}}\right]$$

$$\Rightarrow \quad \sigma_{max} = \sigma_{st}\left[1 + \sqrt{1 + \frac{2hE}{L\sigma_{st}}}\right]$$

$$\Rightarrow \quad \frac{\sigma_{max}}{\sigma_{st}} - 1 = \sqrt{1 + \frac{2hE}{L\sigma_{st}}}$$

On squaring both sides,

$$\left(\frac{\sigma_{max}}{\sigma_{st}} - 1\right)^2 = 1 + \frac{2hE}{L\sigma_{st}}$$

On substituting values,

$$\left(\frac{700}{7.848} - 1\right)^2 = 1 + \frac{2 \times 1.2 \times 1000 \times 130 \times 10^3}{L \times 7.848}$$

$$\Rightarrow \quad L = L_{min} = 5111.713 \text{ mm} = 5.11 \text{ m}$$

So, minimum permissible length of cable is 5.11 m.

Q.8 (c) (i) Solution:

Process of EIA of a project has following stages in our country:

1. **Screening:** It is first and simplest stage in process of project evaluation. In this stage, it is decided whether a particular project requires EIA or not. Screening basically screens out the project that don't require EIA process. Some of the commonly used methods to select projects for EIA are:
   - Use of positive and negative lists
   - Use of project criteria
   - Sensitive area criteria
   - Matrices
   - Initial environment evaluations

2. **Preliminary assessment:** After the first stage of screening, preliminary assessment of a project is done which involves sufficient research, review of available data and expert advice in order to identity the key impacts of project at local environment. In this stage, the extents of impacts of a project is predicted. There can be two types of EIA i.e. 'Comprehensive EIA' in which data of all four seasons of a year is incorporated and 'Rapid EIA' in which there is only one season data. In the stage of preliminary assessment, it is also decided that whether the project requires comprehensive EIA or rapid EIA.
3. **Scoping:** In this stage, EIA team formed after preliminary assessment engages into discussions with various stakeholders of project. This team studies and addresses all issues of importance and concerns raised by various groups. Then, this team selects the primary impacts for main EIA to focus and determines detailed and comprehensive terms of reference for main environment impact assessment.
4. **Main EIA:** In this stage, various aspects of project from environmental perspective are addressed like potential results of project or potential changes in project and extent of these potential changes.

   In simple words, it can be said that this stage involves a cycle of asking questions and further questions until workable solutions are reached. During this stage, key impacts on environment such as changes in air quality, noise levels, impacts on local communities, changes in settlement patterns, changes in employment status, changes in water consumption and availability etc. are formally identified. In this stage, evaluation of predicted adverse impacts is done and it is determined whether they can be mitigated or not. Mitigation may include changing the project side, operating methods, raw materials, disposal methods and routes, engineering designs, waste treatment, phased implementation, landscaping, training, social service etc. Once mitigation measures and costs are identified, a report of EIA is made which has executive summary of project, a description of proposed development, major environment issues, impacts on environment, prediction, mitigation measures and option etc.
5. **Public hearing:** Pollution Control Board conducts a public hearing through various modes of communication, in this stage. In our country, public hearing is not required for following types of projects:
   - Small scale industrial undertakings located in notified or designed industrial areas or area marked for industries under the jurisdiction of industrial development authorities.
   - Widening and strengthening of highways.
   - Modernization of existing irrigation projects.

Q.8 (c) (ii) Solution:

The major air pollutants along, with their source and effects are listed below:

Carbon monoxide (CO)

- It is a colorless, odourless gas that is produced by the incomplete burning of carbon-based fuels including petrol, diesel, and wood.
- It is also produced from the combustion of natural and synthetic products such as cigarettes.
- It lowers the amount of oxygen that enters our blood.
- It slows our reflexes and make us confused and sleepy.

Carbon dioxide (CO_2)

- It is the principle greenhouse gas emitted as a result of human activities such as burning of coal, oil and natural gases.

Chlorofluorocarbons (CFC)

- These are gases that are released mainly from air-conditioning systems and refrigeration system.
- When released into the air, CFCs rise to the stratosphere, where they come in contact with few other gases, which leads to the depletion of the ozone layer that protects the earth from the harmful ultraviolet rays of the Sun.

Lead

- It is present in petrol, diesel, lead batteries, paints, hair dye products, etc. It adversely affects children in particular.
- It causes nervous system damage and digestive problems and, in some cases, cause cancer.

Ozone

- It occurs naturally in the upper layers of the atmosphere particularly in stratosphere.
- This important gas shields the earth from the harmful ultraviolet rays of the Sun.
- However, at the ground level, it is a pollutant with highly toxic effects.
- Vehicles and industries are the major source of ground-level ozone emissions.
- Ozone makes our eyes itchy, burning sensation and watery. It also lowers our resistance to cold and pneumonia.

Nitrogen oxide

- It causes smog and acid rain. It is produced from burning fuels including petrol, diesel, and coal.
- Nitrogen oxide can make children susceptible to respiratory disease in winters.

Suspended particulate matter (SPM)

- It consists of solids in the air in the form of smoke, dust, and vapor that can remain suspended for extended periods and is also the main source of haze which reduces visibility.
- The finer of these particles, when breathed in, can lodge in our lungs and cause lung damage and respiratory problems.

Sulphur dioxide (SO_2)

- It is a gas produced from burning coal, mainly in thermal power plants.
- Some industrial processes, such as production of paper and smelting of metals, produce sulphur dioxide.
- It is a major contributor to smog and acid rain, and can also cause lung diseases.

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